Journal of Advances in Mechanical Engineering and Science, Vol. 1(1) 2015, pp. 1-11

RESEARCH ARTICLE

A New Heuristic for Modern Manufacturing Environment Scheduling Problems

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Received-18 May 2015, Revised-22 June 2015, Accepted-20 July 2015, Published-8 August 2015

ABSTRACT

Modern manufacturing environment scheduling problem has vital criteria to allocate resources based on one or more objective(s). In recent era customer demands products with specialization and customization. So such environment has permutation flow shop configuration due to process job. This work considered those problems with through put related objective. A Taboo search technique based heuristic named BAT, is proposed here to solve the focused flowshop problem. The characteristic of the proposed heuristic was evaluated by solving Taillard benchmark problems. The proposed heuristic outperforms classical heuristics. The results were statistically analysed in which the proposed heuristic produces very less relative deviation from the lower bound.

Keywords: Flowshop, Modern manufacturing, Heuristic, Taboo search technique, ANOVA

1. INTRODUCTION

Modern manufacturing is a production system, which can be found in many manufacturing environments, assembly lines, and processing industries. The Permutation Flow Shop (PFS) is the one in which machines are arranged in a serial order and jobs processing begin in an initial machine, proceed through several intermediary machines, and conclude on a final machine ‘m’. The series arrangement implies a linear structure to the shop.

2. LITERATURE REVIEW

In modern manufacturing environment, scheduling plays a vital role. Scheduling is a decision-making process that is concerned with the assignment of time to a set of jobs for processing through a group of machines in order to best satisfy some criteria. It is known that finding optimal solution for flow shop scheduling problem is a difficult task. Therefore, many researchers focused their efforts on finding near optimal solution within acceptable computation time using heuristics.

A simple algorithm was given by [1], for flowshop scheduling problems in the order of ‘n’ jobs in ‘2’ machines. The NP-completeness of the flow shop-scheduling problem had been discussed widely by [2].

[3] proposed a heuristic with a slope index procedure, which was an effective and simple methodology. The significant work in the development of an efficient heuristic is due to [4] which proposed an algorithm that consists of essentially splitting the given m-machine problem into a series of an equivalent two-machine flow shop problem and solving by Johnson’s rule.

[5] has developed a procedure called ‘rapid access’, which attempts to combine the advantages of Palmer’s slope index and CDS procedures. Though the procedure is found to yield better quality solution than those by Palmer’s and CDS methods, it requires much more computational effort.

[6] have proposed a radically different approach. They solved the make span problem by means of a travelling salesman problem solving method. But [7] proposed a heuristic solution to ‘m’ machine, ‘n’ jobs and yielded better results.

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Double blind peer review under responsibility of DJ Publications
http://dx.doi.org/10.18831/james.in/2015011001

Since the problem is shown to be NP-hard, meta-heuristic algorithms are required efficiently to solve industry size problems. Thus, meta-heuristic algorithms based on Tabu search are developed to efficiently solve for near optimal solutions of the proposed problem [8].

Before presenting how they can be applied to the PFS problem; this technique is exposed in [9]. An application to the PFS problem is proposed in [10]. Tabu search may be useful to find a good or possibly optimal solution of problems. This meta-heuristic approach which has been applied to solve different combinatorial optimization problems, starts with an initial solution and then applies a move mechanism to search neighborhood of current solution to choose the most optimal solution [9]. Apart from these [11,12] developed and suggested various heuristics for permutation flowshop environment and in this paper BAT heuristics is suggested for solving PFS problems.

In any application, the testing parameters are either determined based on experience or by the use of a handbook. It, however, does not provide optimal testing parameters for a particular situation. Some techniques had been constructed to select the optimal or favour conditions. One of the famous statistical analysing tools is ANOVA [13-15]. This article made an attempt to minimize the makespan in permutation flowshop scheduling problem by using Tabu search technique based heuristic.

3. METHODOLOGY -PROPOSED HEURISTIC

The Tabu search technique based heuristic developed for solving flowshop problems is named as BAT Heuristic. BAT heuristic finds the optimal makespan by using mathematical logics in a computerized environment i.e., tabu search technique. This methodology is used to schedule the job sequence in a PFS to obtain an optimal schedule. The methodology of newly proposed heuristic is explained as follows. The generalized N x M permutation flow shop problem is the one in which N number of jobs and M number of machines are employed. Table A1 illustrates its general structure.

3.1. Assumptions

- Pre-emption is not allowed. Once an operation is started on the machine it must be completed before another operation can begin on that machine.
- Each machine is continuously available for assignment, without significant division of the scale into shifts or days and without consideration of temporary unavailability such as breakdown or maintenance.
- Each job is processed through each of the *m* machines once and only once. Furthermore a job does not become available to the next machine until and unless processing on the current machine is completed i.e. splitting of job or job cancellation is not allowed.
- Machine may be idle.

3.2. Notations

M = Number of machines in the PFS
N = Number of jobs in the PFS
P_{ij} = Processing time of j^{th} job in i^{th} machine
T_i= Summation of processing time of N jobs in i^{th}machine
a_{ij}= Summation of processing time of j^{th} job in 1^{st} to $(k-1)^{th}$ machine
b_{ij}= Summation of processing time of j^{th} job in $(k+1)^{th}$to M^{th} machine
A_i= Minimum of a_{ij} for i^{th} machine
B_i = Minimum of b_{ij} for i^{th} machine
S_i = Summation of T_i, A_i and B_i for i^{th} machine
LB = Maximum of S_i
Z = Pivot Machine
Z_A, Z_B = Pivot Jobs

3.3. Algorithm

Step 1: Assign the processing time of '*N*' jobs in '*M*' machines to frame the *N* x *M* matrix of the PFS problem.

Step 2: Calculate a_{ij} and b_{ij}values using the equations (1) and (2).

$$a_{ij} = \sum_{i=1}^{k-1} P_{ij} \tag{3.1}$$

$$b_{ij} = \sum_{i=k+1}^{m} P_{ij} \tag{3.2}$$

Step 3: Calculate T_i, A_i, and B_i values using the equations (3), (4) & (5).

$$T_i = \sum_{j=1}^{n} P_{ij} \tag{3.3}$$

$$A_i = \min(a_{ij}) \tag{3.4}$$

$$B_i = \min(b_{ij}) \tag{3.5}$$

Step 4: Calculate the S_i values for '*M*' machines using equation (6).

$$S_i = T_i + A_i + B_i \tag{3.6}$$

Step 5: Find the lower bound value (*LB)* value for the considered *N* x *M* PFS problem by using the equation (7).

$$LB = \max(S_i) \tag{3.7}$$

Step 6: The pivot machine (*Z*)can be identified by the below stated condition in equation (8).

$$\text{if } (\text{LB} == \text{T}_\text{k} + \text{A}_\text{k} + \text{B}_\text{k}) \Rightarrow \text{Z} = \text{k} \tag{3.8}$$

Step 7: The pivot jobs *ZA* and *ZB* can be identified by using the condition stated in equation (9) and (10).

$$\text{if } (\text{A}_\text{k} == \text{a}_\text{kr}) \Rightarrow \text{ZA} = \text{r} \tag{3.9}$$

$$\text{if } (\text{B}_\text{k} == \text{b}_\text{ks}) \Rightarrow \text{ZB} = \text{s} \tag{3.10}$$

Step 8: Place the ZA and ZB pivoted jobs in the sequence, which abide the following condition. Suppose for the pivoted job ZA, the value of $\text{Z} \neq 1$ && $\text{ZA} \neq 1$ then ZA will be placed at end of the sequence. Suppose for the pivoted job ZB, the value of $\text{Z} \neq M$ && $\text{ZB} \neq N$ then ZB will be placed in the beginning of the sequence.

Step 9: After the successful completion of step 9 eliminate the *ZA* and *ZB* jobs from the *N* x *M* PFS problem.

Step 10: Apply taboo search technique from step 3 to step 10. The possible number of iterations will be N to 2N.

Step 11: Arrange the jobs in a sequence according to the pivoting conditions.

Step 12: Find the optimal schedule using process flow table.

4. RESULTS AND DISCUSSIONS

The analysis is carried out by means of equations in (3.1), (3.2), (3.3), (3.4), (3.5), (3.6), (3.7), (3.8), (3.9), (3.10) and(3.11).The bench mark problems proposed by [15] are tested against the newly proposed BAT heuristic. The experimentations were carried out with the problem size of 20x5, 20x10 and 20x20. The makespan performance of Palmer, Gupta, CDS and CR heuristics were obtained in minutes for similar Morden manufacturing environments (20x5, 20x10 and 20x20). The makespan performances of heuristics (including BAT heuristics) are tabulated in table A2 for 5 machines, 20 jobs problem (5x20), table A3 for 10 machines, 20 jobs problem (10x20) and table A4 for 20 machines, 20 jobs problem (20x20). The relative deviation of BAT heuristic with the existing heuristics with respect to the lower bound (*LB*) is highlighted in table A5.

The relative deviation of heuristic from lower bound is calculated from equation (1).

$$\text{RD}(\%) = ((\text{Makespan} - \text{LB}) / \text{Makespan}) * 100 \tag{3.11}$$

The makespan performances by considered heuristics for the problems 5x20, 10x20, and 20x20 are graphically represented in figure B1, figure B2 and figure B3 respectively. Figure B4 illustrates the relative deviation of proposed BAT heuristics with other existing heuristics which is considered in this work. It is obvious that the proposed BAT heuristic (refer figure B1 – B3) yielded minimal makespan. In other words the BAT heuristics yielded very low makespan compared to other existing heuristics (Palmer, Gupta, CDS and CR heuristics). From figure B4, it is observed that the relative deviation of the BAT heuristic is lower by about 16.55% from the lower bound compared to other existing heuristics.

5. ANALYSIS OF VARIANCE (ANOVA)

For statistical evaluation of proposed heuristic, the one way ANOVA is used. The lower Bound for the Palmer, Gupta, CDS, CR

and BAT heuristics were characterised in the one way ANOVA in the software MINITAB16 environment. This analysis is conducted with the aim to determine the optimal noise level by "smaller as best". It is understood that the significant level can be identified from table A4, The obtained p-value is 0.733 at confidence level 95%.

Thirty trials had been made for conducting the experiments. The mean, standard deviation and the makespan yielded by heuristics are tabulated in table A7. It is observed in table A7 that the BAT heuristics out performs other heuristics considered here for evaluation in yielding minimum makespan.

The analysis using Hsu's MCB (Multiple Comparison with the Best) method is tabulated in table A7 and graphically illustrated in figure B5 and figure B6 through box plot and scatter plot respectively. This analysis again proves that the BAT heuristic maintains its level of searching neighbour well in finding the best.

The residual plots for the Palmer, Gupta, CDS, CR and BAT heuristics are shown in figure B7. In this analysis, the value of f is small (0.5) and the value of p is (0.733) and is greater than 0.05 (p = 0.733 > 0.05). Hence, the BAT heuristic is acceptable.

6. CONCLUSION

It is observed that many modern manufacturing environment has permutation flow shop setups. So this study focused on permutation flowshop. The Taboo Search based heuristic was developed in the name of BAT heuristic and the same was proposed to solve the permutation flow shop problems. The BAT heuristics was tested with Taillard bench mark problems. The obtained results were tabulated and graphically represented.

The results were compared with well known heuristics viz Palmer, CR, Gupta, and CDS heuristics. The proposed BAT heuristic has the application of Taboo search technique which improves the search of optimal neighbour in a sequence. The performances of heuristics along with BAT were statistically examined by one way ANOVA in MINITAB 16 software. It resulted that the BAT heuristic has a relative deviation of 16.55% from the LB compared to other heuristics considered here for evaluation. It is understood that as the BAT heuristic yielded solution has value of p as 0.733 which is greater than f-value (Refer table A6), the newly proposed BAT heuristic can be accepted for solving permutation flowshop problems with through put related objectives.

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APPENDIX A

Table A1.General structure of *n* x *m* |ffs problem

Job	Processing Time On Machines				
	M_1	M_2	M_3	…	M_M
J_1	P_{11}	P_{12}	P_{13}	…	P_{1M}
J_2	P_{21}	P_{22}	P_{23}	…	P_{2M}
J_3	P_{31}	P_{32}	P_{33}	…	P_{3M}
. .	. .	. .	. .	. .	. .
J_N	P_{N1}	P_{N2}	P_{N3}	…	P_{NM}

Table A2.Comparison of makespan for 5 machines, 20 jobs

SEED	LB	Palmer	Gupta	CDS	CR	BAT
Seed 1	1232	1384	1425	1409	1377	1336
Seed 2	1290	1439	1424	1424	1468	1360
Seed 3	1073	1162	1255	1255	1379	1185
Seed 4	1268	1490	1485	1485	1548	1338
Seed 5	1198	1360	1367	1367	1387	1273
Seed 6	1180	1344	1387	1387	1411	1280
Seed 7	1226	1400	1403	1403	1381	1303
Seed 8	1170	1313	1395	1395	1404	1313
Seed 9	1206	1426	1360	1360	1425	1239
Seed 10	1082	1229	1196	1196	1284	1170

Table A3.Comparison of makespan for 10 machines, 20 Jobs

SEED	LB	Palmer	Gupta	CDS	CR	BAT
Seed 1	1448	1790	1829	1829	1887	1752
Seed 2	1479	1948	2021	2021	2121	1906
Seed 3	1407	1729	1819	1773	1786	1884
Seed 4	1308	1585	1695	1678	1628	1585
Seed 5	1325	1648	1781	1781	1893	1597
Seed 6	1290	1527	1875	1813	1835	1518
Seed 7	1388	1735	1826	1826	1659	1628
Seed 8	1363	1763	2056	2031	1878	1735
Seed 9	1472	1836	1831	1831	1851	1831
Seed 10	1356	1898	2010	2010	1878	1855

Table A4.Comparison of makespan for 20 machines, 20 Jobs

SEED	LB	Palmer	Gupta	CDS	CR	BAT
Seed 1	1911	2818	2808	2559	2700	2571
Seed 2	1711	2331	2564	2285	2600	2236
Seed 3	1844	2678	2977	2565	2818	2510
Seed 4	1810	2629	2603	2434	2550	2438
Seed 5	1899	2704	2733	2506	2815	2452
Seed 6	1875	2572	2707	2422	2518	2370
Seed 7	1875	2456	2683	2489	2730	2398
Seed 8	1880	2435	2523	2362	2582	2383
Seed 9	1840	2754	2617	2414	2538	2392
Seed 10	1900	2633	2649	2469	2472	2372

Table A5.Relative Deviation Towards Lower Bound

Heuristics	Palmer	Gupta	CDS	CR	BAT
Relative deviation (%)	20.32	23.24	20.82	23.0 8	16.55

Table A6.One way ANOVA –makespan versus heuristic

Source	Degree of Freedom	Sum of Squares	Mean of Squares	F- value	P- value	Inference
Factor	4	538170	134543	0.5	0.733	Significant
Error	145	38751652	267253			
Total	149	39289822				

Table A7.Mean based on Pooled Standard Deviation (SD)

Level	N	Mean	SD
PALMER HEURISTIC	30	1900.5	544.0
GUPTA HEURISTIC	30	1976.8	562.3
CDS HEURISTIC	30	1892.6	459.9
CR HEURISTIC	30	1960.1	527.7
BAT HEURISTIC	30	1807.0	483.8
Pooled SD			517.0

APPENDIX B

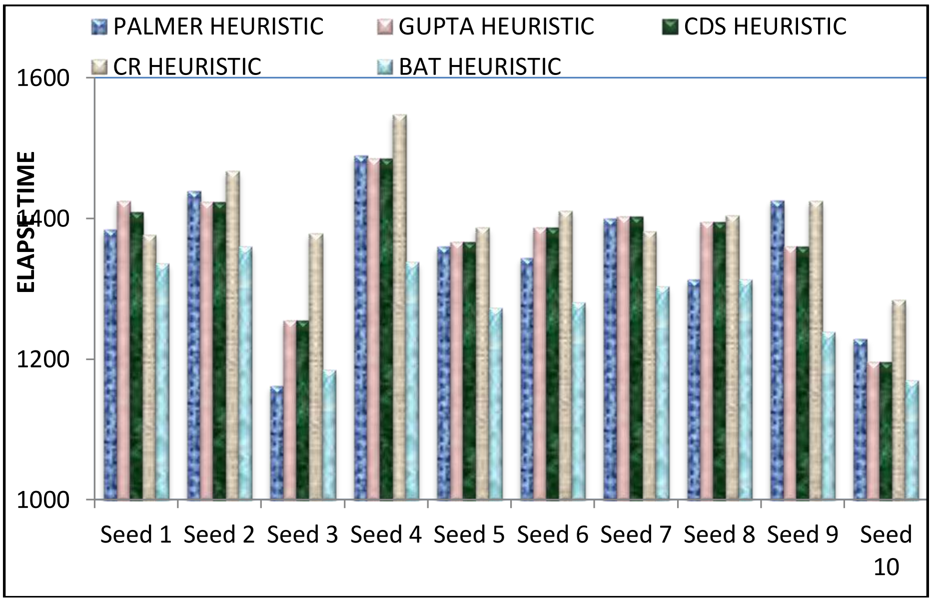

Figure B1.Comparison of makespan for 5 machines, 20 jobs

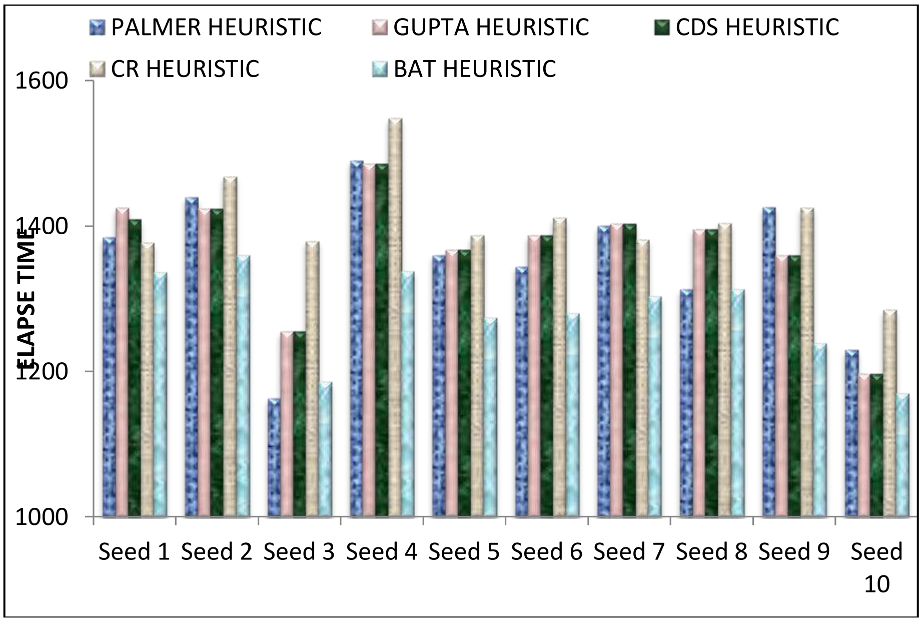

Figure B2.Comparison of makespan for 10 machines, 20 jobs

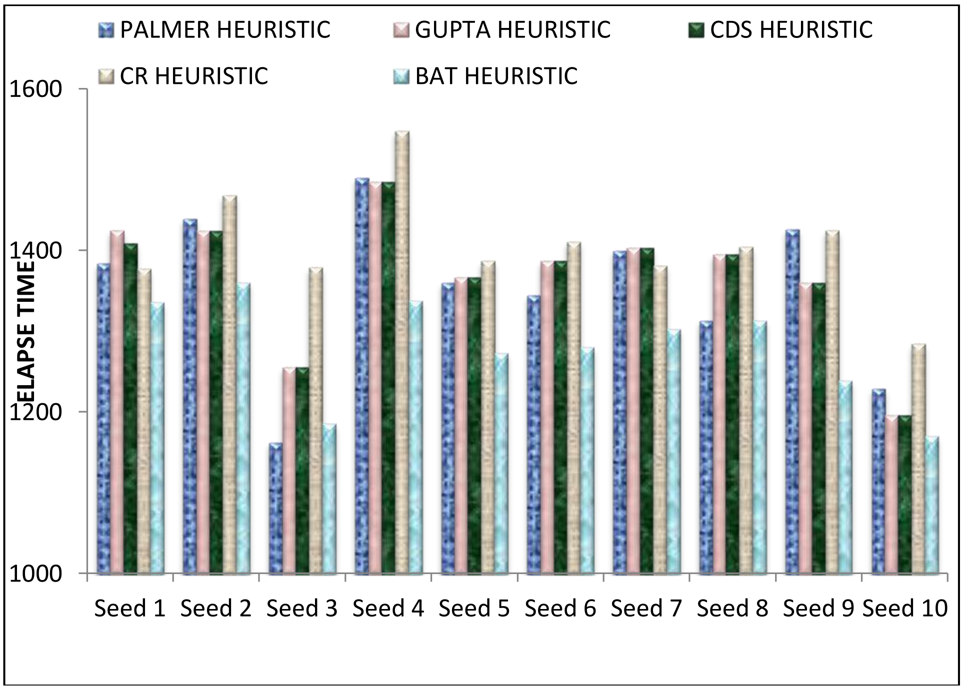

Figure B3.Comparison of makespan for 20 machines, 20 jobs

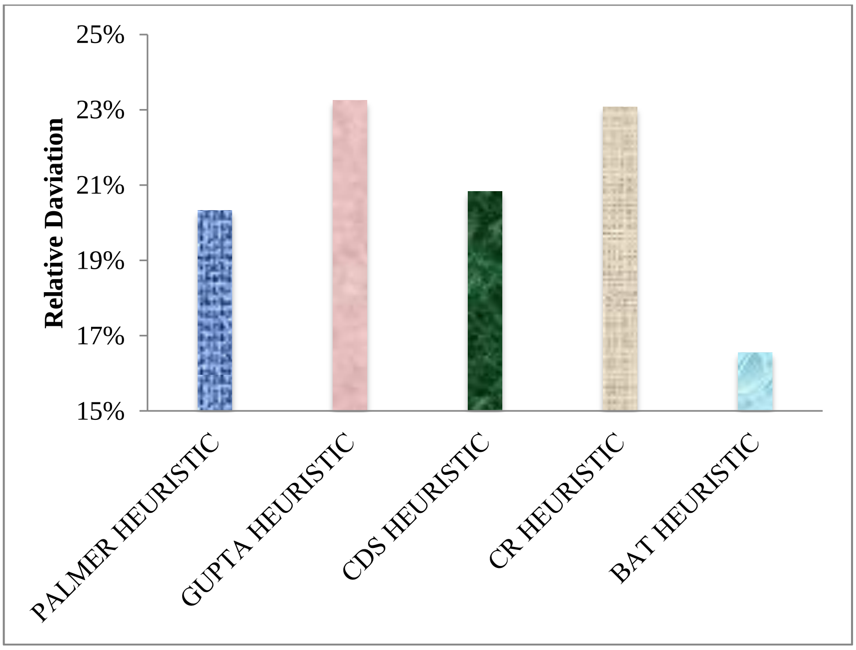

Figure B4.Relative deviation towards lower bound

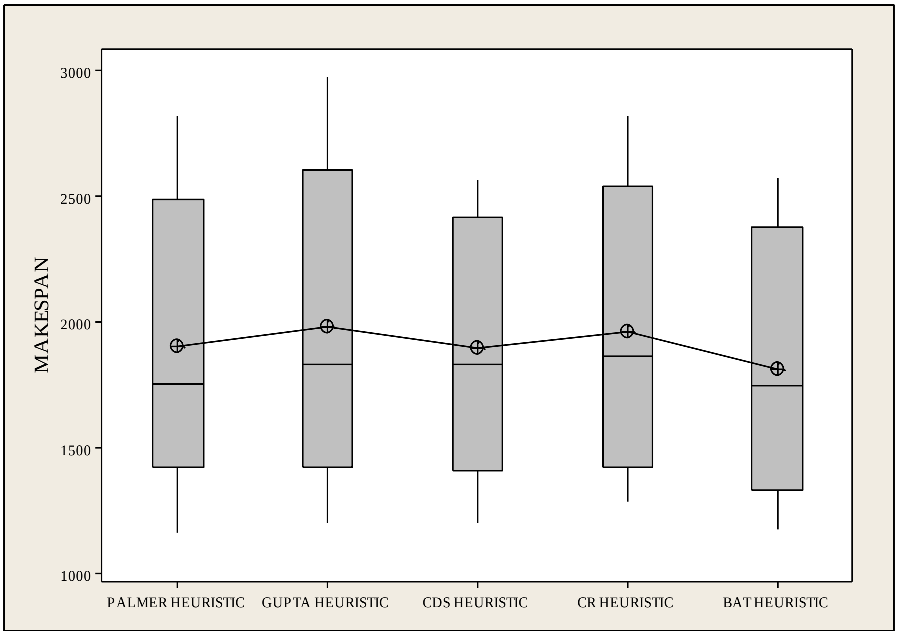

Figure B5.Box plot of MCB

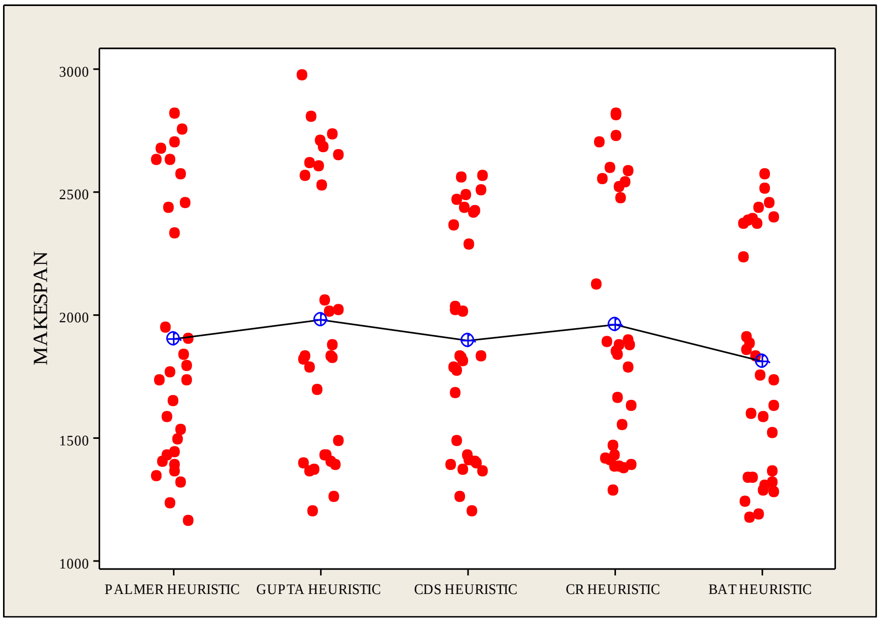

Figure B6.Individual value plot of MCB

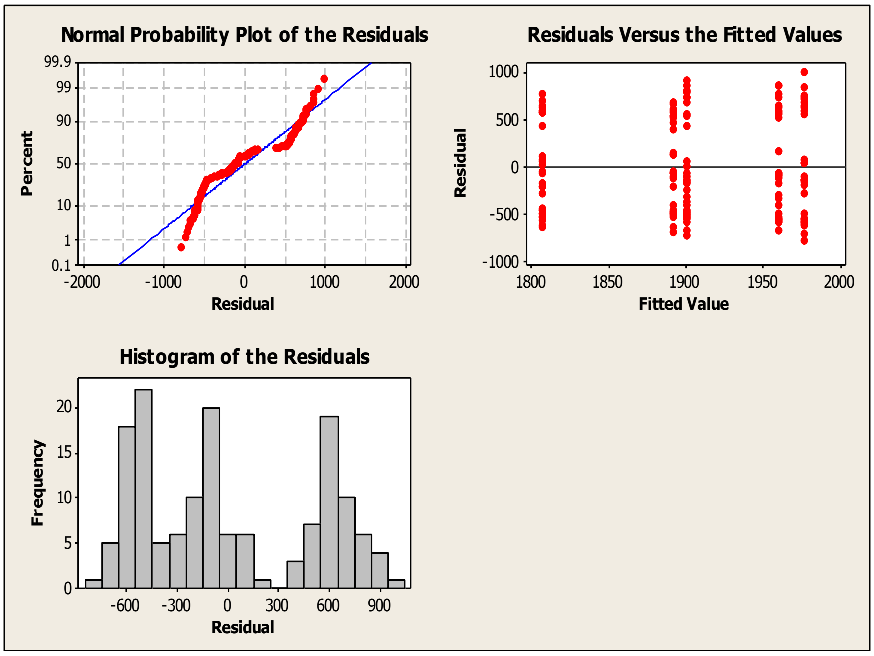

Figure B7. Residual plots for MCB